Rural Electrification Administration
Telephone Engineering and Construction Manual

Section 426
Issue 2
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SUBSCRIBER LOOP COMPUTATIONS
DESIGN-BY-LOSS METHOD

CONTENTS

1. GENERAL

1.1 This section provides REA financed telephone companies, consulting engineers, contractors and other interested parties with technical information for use in the design and construction of telephone systems. The design-by-loss method of making subscriber loop computations is discussed.

1.2 This revised issue replaces REA TE&CM 426, Issue No. 1, dated October 1965, and reflects changes in design objectives outlined in REA TE&CM 424, "Design of Two-Wire Subscriber Loop and PABX Trunk Plant," Issue No. 3, dated May 1973.

1.3 The design procedure in Section 424 is such that no transmission calculations have to be made where typical cable outside plant facilities are being used. Reference to the applicable tables in Section 424 shows the maximum length of outside plant facilities which meets the transmission objective or, in the case of mixed gauges, the maximum outside plant dc loop resistance. The computation procedures herein are intended to be a supplement to Section 424.

1.4 The design-by-loss method is used in Section 424 to compute the 1000 Hertz loss to any subscriber in the loop. This method, based on the actual transmission loss in the loop, not only makes it possible to know the actual loss of the loop in the design, but also to verify its performance by measurement. This can be done initially, and thereafter, whenever transmission difficulties are being experienced or circuit rearrangements are being made. The one-man equipment which can be used to verify the design is the loop checker, which consists of a reference tone generator at the central office and a portable voltmeter which can be connected to any subscriber loop at a residence or any other convenient location.

2. COMPUTATION PROCEDURE

2.1 The computation procedure for obtaining the 1000 Hertz loss, using the design-by-loss method, is carried out as follows:

Total 1000 Hz Circuit Loss = Length (in kf or mi) times the attenuation at 1000 Hz (in dB/kf or dB/mi.) for each different type facility

+ Bridged Tap Isolator Loss
+ Bridged Tap Loss
+ Drop Wire Loss
+ Subscriber Carrier Loss
+ VF Repeater Gain
+ Long Line Adapter Loss
+ Loop Extender Loss
+ Reflection Loss
+ Other Losses or Gains

2.2 The 1000 Hertz loss (or gain) for each of the facilities and equipment in paragraph 2.1 is given in Tables I - IV. Table V gives a summary of all abbreviations used in this TE&CM.

2.3 Where loaded loops are extended with nonloaded cable, the loaded portion of the loop is taken to be that between 0.5 end sections. That is, the loaded loop begins at 0.5 end section at the central office end (0.4 to 0.6 is acceptable) and ends at 0.5 end section after the <u>last</u> loading point.

2.4 All applicable information in Tables I - IV for D-66 loaded cables applies to H-88 loaded cables since their attenuation rates at 1000 Hertz are equal.

2.5 The dc resistance and attenuation information and all examples shown herein are based on a temperature of 68°F (20°C). Since resistance and attenuation increase with an increase in temperature, the data given herein must be modified for temperatures other than 68°F. Change the 68°F, 1000 Hertz attenuation by ± 1% for every ± 10°F change in temperature for nonloaded cables and open wire lines. For loaded cables, a change of only ± 5°F necessitates modifying the attenuation by ± 1%. DC loop resistance is affected by temperature change in the same proportion as the loaded cable attenuation.

2.6 For purposes of computation, a reflection loss for dissimilar facilities should be assessed only when the loss of each of the facilities at 1000 Hertz is 1 dB or greater. While this simplified approach is not theoretically rigorous, it is a practical one and the loss in accuracy is not significant.

3. EXAMPLES

3.1 Examples 1-15 illustrate the computational procedure for a number of typical outside plant facilities. The central office loss of 0.5 dB is not shown and is not included in the subscriber loop loss budget.

TABLE I

FACILITY LOSS AT 1000 HERTZ

FACILITY		dB/mi	dB/kf	dB/km
26-Ga. NL HC[1] Cable		2.90	.549	1.80
24-Ga. NL " "		2.28	.432	1.42
22-Ga. NL " "		1.80	.341	1.12
19-Ga. NL " "		1.25	.237	.78
26-Ga. D-66[2], H-88 HC Cable		1.86	.352	1.16
24-Ga. D-66, H-88 " "		1.23	.233	.76
22-Ga. D-66, H-88 " "		0.82	.156	.51
19-Ga. D-66, H-88 " "		0.44	.083	.27
.080" - 25% C-S Wire	Open Wire	0.30	.057	.186
.091" - Aluminum Wire	Open Wire	.28	.053	.174
.080" - 30% C-S Wire	Open Wire	.28	.053	.174
.080" - 40% " "	Open Wire	.23	.044	.143
.102" - 30% " "	Open Wire	.20	.038	.124
.104" - 40% " "	Open Wire	0.16	.030	.099
.104" - CU C-S Wire	Open Wire	.078	.015	.048
.109" - 135 Steel Wire	Open Wire	.31	.059	.037

NOTES:

1. Indicates air core or filled miltipaired, shielded cables with 0.083 microfarads/mile average mutual capacitance.
2. Attenuation rates for D-66 and H-88 loading are approximately the same at 1000 Hertz.

TABLE II

AVERAGE DC CONDUCTION LOOP RESISTANCE AT 68°F (20°C)

FACILITY		OHMS/mi	OHMS/kf	OHMS/km
26-Ga HC Cable		440.0	83.33	273.4
24-Ga HC Cable		274.0	51.89	170.3
22-Ga HC Cable		171.0	32.39	106.3
19-Ga HC Cable		85.0	16.10	52.8
.109" - 85 Steel Wire	Open Wire	68.0	12.88	42.3
.109" - 135 Steel Wire	Open Wire	76.5	14.49	47.5
.109" - 195 Steel Wire	Open Wire	77.6	14.70	48.2
.109" - 190 Steel Wire	Open Wire	94.2	17.84	58.5
.134" - 135 Steel Wire	Open Wire	50.4	9.60	31.3
.104" - 30% C-S Wire	Open Wire	32.3	6.12	20.1
.104" - 40% C-S Wire	Open Wire	24.6	4.66	15.3
.102" - 30% C-S Wire	Open Wire	35.9	6.8	22.3
.080" - 25% C-S Wire	Open Wire	61.4	11.63	38.2
.091" - Aluminum Wire	Open Wire	60.9	11.53	37.8
.080" - 30% C-S Wire	Open Wire	54.5	10.32	33.9
.080" - 40% C-S Wire	Open Wire	41.6	7.88	25.8
.104" - CU H.D.	Open Wire	10.3	1.95	6.4
66 mH Coil		6.0 Ohms/Coil		Maximum
88 mH Coil		8.5 Ohms/Coil		Maximum
Bridged Tap Isolator		20.0 Ohms/Coil		Maximum
Voice Frequency Repeaters		60.0 Ohms Nominal 120.0 Ohms Maximum BOR (22-Ga.) 32.4 Ohms/kf (24-Ga.) 51.9 Ohms/kf		

TABLE III

MISCELLANEOUS LOSSES AND GAINS AT 1000 HERTZ

EQUIPMENT OR FACILITY	ABBREVIATION	TRANSMISSION LOSS OR GAIN
Entrance to Central Office Loss	COL	0.5 dB
Long Line Adapter Loss	LLAL	0.5 dB
Loop Extender Loss	LEL	0.5 dB Maximum (0.1-0.2 dB Nominal)
Bridged Tap Isolator Loss	BTIL	0.3 dB
Rep. BOR Loss	BORL	
22 Gauge	BORL	0.152 dB/kf
24 Gauge	BORL	0.235 dB/kf
PBX Switchboard Loss	PBXSL	0.5 dB
PCM Subscriber Carrier Loss	PCM CXR	2.0 dB
Station Carrier Loss	SCXR	4.0 dB
Others Carrier Loss	CXR	0-4.0 dB
Bridged Tap Loss	BTL	0.25 dB/kf
Drop Wire Loss	DWL	0.10 dB/kf
Net Repeater Gain	NRG	-(AS SET)
Reflection Loss	RFL	SEE TABLE IV

TABLE IV

REFLECTION LOSSES IN DB AT 1000 CPS FOR DISSIMILAR FACILITIES

	FACILITY	CABLE AND FIGURE "8" RDW: 26 GAUGE D66 H88	24 GAUGE N.L.	24 GAUGE D66 H88	22 GAUGE N.L.	22 GAUGE D66 H88	19 GAUGE N.L.	19 GAUGE D66 H88	OPEN-WIRE: 109 STEEL 85-135	109 STEEL 190	COPPER-STEEL 30% 104	COPPER-STEEL 40% 104	COPPER-STEEL 30% 080	COPPER-STEEL 40% 080	104 COPPER	RDW (FORMER TYPE): 22 GAUGE N.L.	22 GAUGE D66 H88	19 GAUGE N.L.	19 GAUGE D66 H88	600 OHMS
CABLE & FIGURE "8" RDW	26 N.L.	-0.2	0.1	-0.3	0.3	-0.4	0.9	-0.5	0	0.1	-0.1	-0.1	0	-0.1	-0.2	0.4	-0.4	1.0	-0.6	-0.4
	26 D66 or H88	X		0	0.5	0	1.2	0	0	0	0.2	0.2	0	0.1	0.4	0.7	0.1	1.5	0	0.4
	24 N.L.		X	-0.1	0.1	-0.3	0.5	-0.5	0.2	0.4	-0.2	-0.2	0.2	-0.1	-0.3	0.2	-0.3	0.6	-0.5	-0.6
	24 D66 or H88			X	0.2	0	1.0	0	0	0	0.1	0.1	0	0	0.3	0.6	0.1	1.2	0	0.4
	22 N.L.				X	0	0.1	-0.2	0.8	0.9	0	0	0.5	0.2	-0.3	0	-0.2	0.3	-0.2	-0.6
	22 D66 or H88					X	0.7	0	0	0	0	0	-0.2	-0.1	0.2	0.3	0.1	0.9	0	0.3
	19 N.L.						X	0.5	1.5	1.8	0.5	0.4	1.1	0.7	0	0	0.3	0	0.4	-0.4
	19 D66 or H88							X	0	0	-0.1	0	-0.3	-0.1	0.1	0.2	0	0.8	0	0.3
OPEN WIRE	109 Steel (85 or 135)								X	0	0.2	0.3	0.1	0.2	0.4	1.1	0.1	1.8	0	0.6
	109 Steel (190)									x	0.3	0.4	0.1	0.2	0.6	1.3	0.2	2.0	0	0.7
	104 C.S. 30%										X	0	0.2	0	0	0.3	-0.1	0.7	-0.2	0
	104 C.S. 40%											X	0.2	0.1	0	0.1	0	0.6	-0.1	-0.1
	080 C.S. 30%												X	0	0.2	0.7	-0.1	1.3	-0.2	0.1
	080 C.S. 40%													X	0.1	0.4	-0.1	1.0	-0.2	0
	104 CU														X	-0.2	0.1	0.2	0.2	0
RDW (FORMER TYPE)	22 N.L.															X	0	0.1	0	-0.6
	22 D66 or H88																X	0.6	0	0.2
	19 N.L.																	X	0.6	-0.3
	19 D66 or H88																		X	0.2

TABLE V

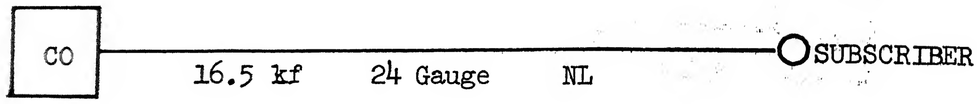
ABBREVIATIONS

Hz	Hertz
dB	decibel
kf	kilofeet
mi	mile
km	kilometer
VF	voice frequency
NL	non-loaded
HC	high capacitance
Ga	gauge
mH	milliHenry
BOR	build out resistance
CO	central office
COL	central office loss
LLAL	long line adapter loss
LEL	loop extender loss
BTIL	bridged tap isolator loss
BORL	build out resistance loss
PBXSL	private branch exchange switchboard loss
PCM	pulse code modulation
CXR	carrier
PCMCXR	pulse code modulation subscriber carrier
SCXR	station carrier
BTL	bridged tap loss

ABBREVIATIONS (CONTINUED)

DWL	drop wire loss
NRG	net repeater gain
RFL	reflection loss
VFR	voice frequency repeater
NRR	negative resistance repeater
AGC	automatic gain control
SAI	serving area interface
LP	load point
RDW	rural distribution wire

EXAMPLE 1



1. DC LOOP RESISTANCE

REFERENCE

16.5 kf, 24 gauge x 51.89 ohms/kf — TABLE II

= 856 ohms

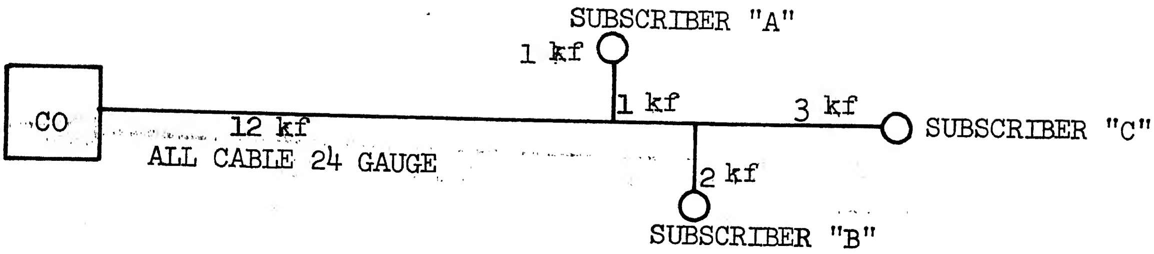
2. 1000 Hz LOSS

16.5 kf, 24 gauge x 0.432 dB/kf — TABLE I

= 7.1 dB

This example shows the simplest transmission path between the central office and a subscriber. Note that the loop resistance is less than the maximum limit of 1700 ohms and that the total 1000 Hz. loss is less than the maximum limit of 8 dB.

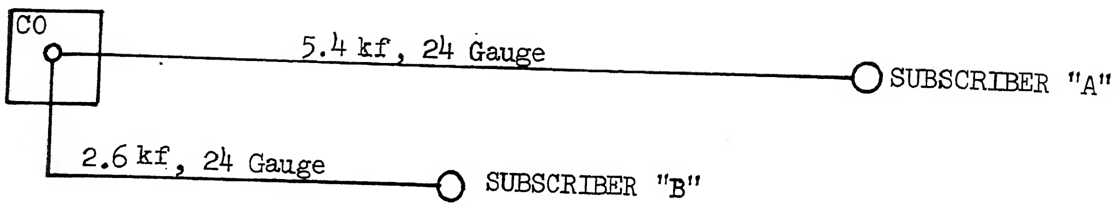
EXAMPLE 2



1. DC LOOP RESISTANCE (SUBSCRIBER C)			REFERENCE
(12 + 1 + 3) kf, 24 gauge x 51.89 ohms/kf = 830 ohms			TABLE II
2. 1000 Hz. LOSS (SUBSCRIBER C)			
(12 + 1+3) kf, 24 gauge x 0.432 dB/kf	=	6.91 dB	TABLE I
BTL (1+2) x 0.25 dB/kf	=	0.75 dB	TABLE III
Total 1000 Hz Loss	=	7.66 dB	
3. 1000 Hz LOSS (SUBSCRIBER A)			
(12 + 1) kf, 24 gauge x 0.432 dB/kf	=	5.62 dB	TABLE I
BTL (1 + 3 + 2) kf x 0.25 dB/kf	=	1.50 dB	TABLE II
Total 1000 Hz Loss	=	7.12 dB	

Example 2 illustrates the use of bridged taps.

EXAMPLE 3



1. DC LOOP RESISTANCE

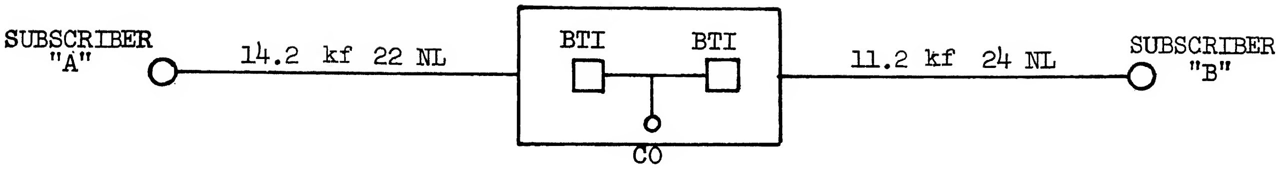
			REFERENCE
SUBSCRIBER A	-	5.4 kf, 24 gauge x 51.89 ohms/kf	TABLE II
		= 280 ohms	
SUBSCRIBER B	-	2.6 kf, 24 gauge x 51.89 ohms/kf	TABLE II
		= 135 ohms	

2. 1000 HZ LOSS (SUBSCRIBER A)

5.4 kf, 24 gauge NL	x 0.432 dB/kf	= 2.33 dB	TABLE I
BTL	2.6 kf x 0.25 dB/kf	= 0.65 dB	TABLE III
	Total 1000 Hz Loss	2.98 dB	

This example shows another use of bridged taps.

EXAMPLE 4



1. DC LOOP RESISTANCE

REFERENCE

SUBSCRIBER A - 14.2 kf, 22 gauge x 32.39 ohms/kf + 20 ohms/BTI — TABLE II

= 480 ohms

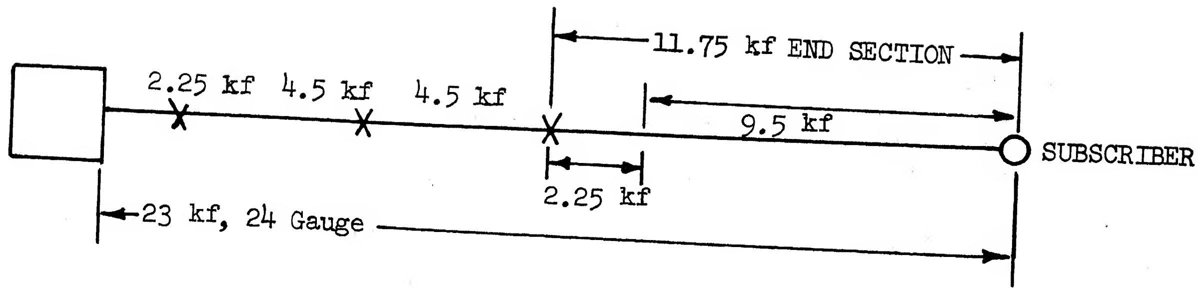
SUBSCRIBER B - 11.2 kf, 24 gauge x 51.89 ohms/kf + 20 ohms/BTI — TABLE II

= 601 ohms

2. 1000 HZ LOSS

SUBSCRIBER A - 14.2 kf, 22 gauge x 0.341 dB/kf = 4.84 dB

EXAMPLE 5



1. DC LOOP RESISTANCE

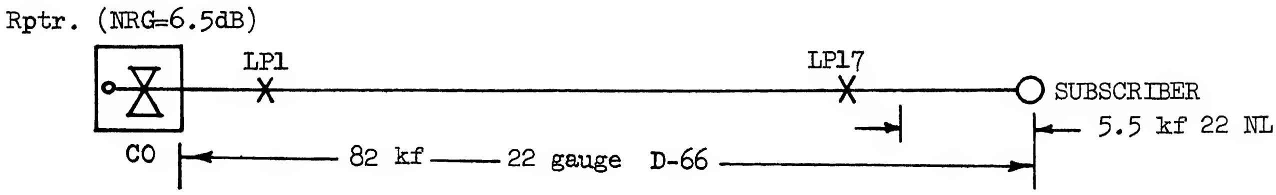
			REFERENCE
23 kf, 24 gauge x 51.89 ohm/kf	=	1193 ohms	TABLE II
3 LP's x 6 ohms/LP	=	18 ohms	TABLE III
Total Loop Resistance		1211 ohms	

2. 1000 HZ LOSS

13.5 kf, 24 gauge D-66 x 0.233 dB/kf	=	3.15 dB	TABLE I
9.5 kf, 24 gauge NL x 0.432 dB/kf	=	4.10 dB	TABLE I
Reflection Loss 24-D-66/24-NL	=	-0.1 dB (ignore)	TABLE IV
Total 1000 Hz Loss		7.25 dB	

Inductive loading is used here at points marked with an X to reduce the transmission loss. Loaded cable is assumed to be that between 0.5 end sections. Any remaining is considered non-loaded. Note that the end section here is less than the 12 kf maximum limit.

EXAMPLE 6a



1. DC LOOP RESISTANCE

			REFERENCE
82 kf, 22 gauge x 32.39 ohm/kf	=	2656 ohms	TABLE II
17 LP's x 6.0 ohms/LP	=	102 ohms	TABLE II
VFR-NRR Negative Resistance Rptr.	=	60 ohms	TABLE II
Total DC Loop Resistance		2818 ohms	

2. 1000 HZ LOSS

76.5 kf, 22-D-66 x 0.156 dB/kf	=	11.93 dB	TABLE I
5.5 kf, 22-NL x 0.341 dB/kf	=	1.88 dB	TABLE I
Loop Extender Loss	=	0.2 dB	TABLE III
NRG	=	-6.5 dB	
Total 1000 Hz Loss		7.51 dB	

EXAMPLE 6b (SAME AS 6a EXCEPT USING AGC REPEATER)

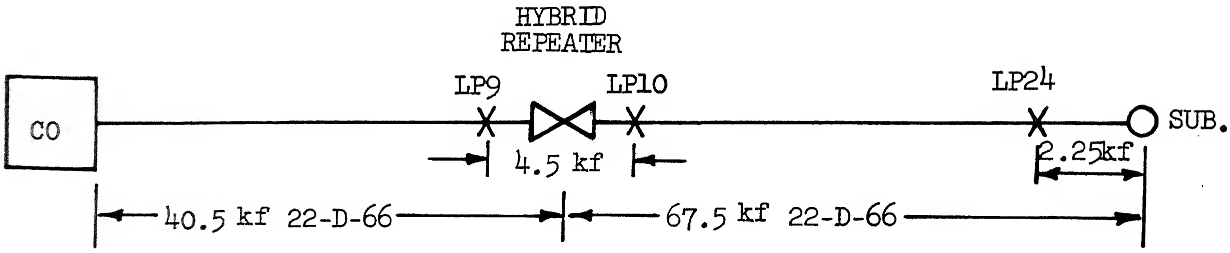
1000 HZ LOSS

76.5 kf, 22-D-66 x 0.156 dB/kf	=	11.93 dB
5.5 kf, 22-NL x 0.341 dB/kf	=	1.88 dB
Loop Extender Loss	=	.2 dB
AGC Gain	=	- 8.00 dB
Total 1000 Hz Loss		6.01 dB

6a. Because of the very long transmission path, it is necessary to use a voice frequency repeater here for amplification to keep the transmission loss less than the 8 dB limit. In addition, a loop extender is needed to improve signaling since the loop resistance is greater than 1700 ohms.

6b. This example is identical to 6a except that it illustrates the use of an automatic gain control (AGC) repeater. The repeater manufacturer's instructions should be followed in calculating the gain of this type repeater.

EXAMPLE 7



1. DC LOOP RESISTANCE

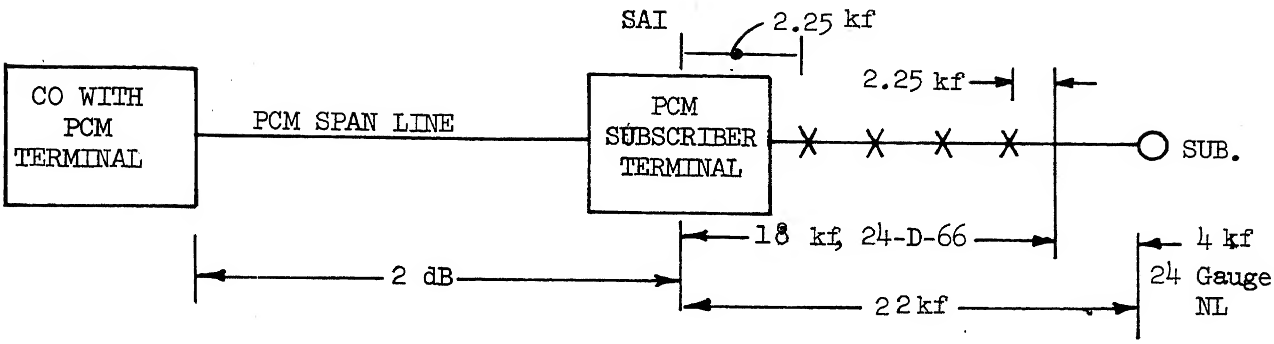
			REFERENCE
108 kf, 22 gauge x 32.39 ohm/kf	=	3498 ohms	TABLE II
24 LP's x 6 ohms/LP	=	144 ohms	TABLE II
VFR	=	120 ohms	TABLE II
Total DC Loop Resistance		3762 ohms	

2. 1000 HZ LOSS

			REFERENCE
108 kf, 22-D-66 x 0.156 dB/kf	=	16.85 dB	TABLE I
Loop Extender	=	.2 dB	
NRG		-10.0 dB	
Total 1000 Hz Loss		7.05 dB	

Example 7 illustrates the use of a hybrid repeater. Note that the resistance is 120 ohms instead of the 60 ohms associated with a negative resistance repeater.

EXAMPLE 8



1. DC LOOP RESISTANCE

22 kf, 24 gauge x 51.89 dB/kf	=	1142 ohms	TABLE II
4 LP's x 6.0 ohms/LP	=	24 ohms	TABLE II
Total DC Loop Resistance		1166 ohms	

REFERENCE (column heading above TABLE II entries)

2. 1000 HZ LOSS

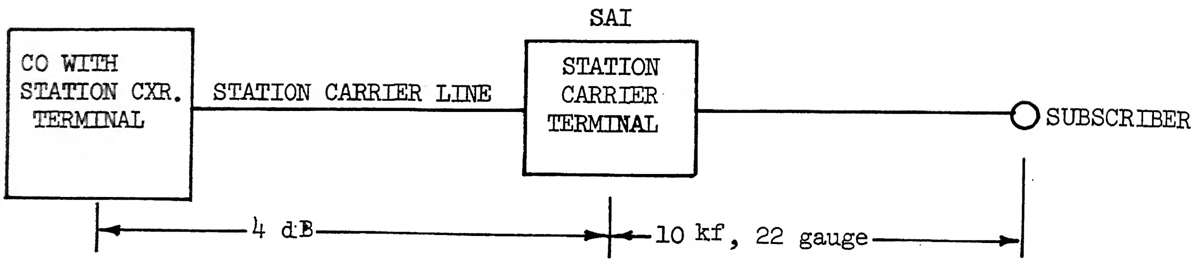
18 kf, 24-D-66	x 0.233 dB/kf	=	4.19 dB	TABLE I
4 kf, 24-NL	x 0.432 dB/kf	=	1.73 dB	TABLE I
Reflection Loss 24-D-66/24NL		=	-0.10 dB (ignore)	TABLE IV

REFERENCE

PCM CXR Loss =

Total 1000 Hz Loss

EXAMPLE 9



1. DC LOOP RESISTANCE

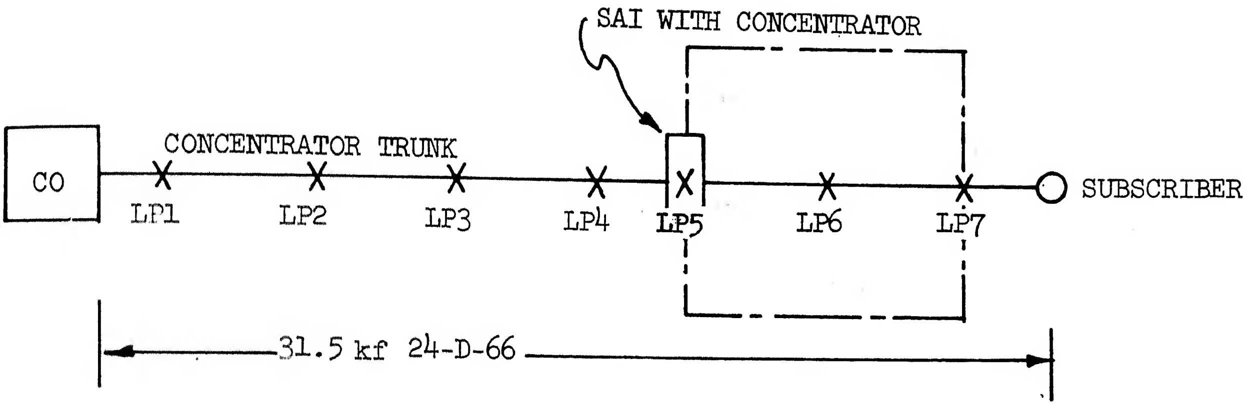
10 kf, 22 gauge NL x 32.39 ohms/kf = 324 ohms		REFERENCE
		TABLE II

2. 1000 HZ LOSS

10 kf, 22 gauge NL x 0.341 dB/kf	= 3.41 dB
Subscriber Carrier Loss	= 4.00 dB
Total 1000 Hz Loss	7.41 dB

The use of station carrier is illustrated in this example. Note that the maximum resistance to the subscriber is determined by the particular type of station carrier used. Manufacturer's data should be consulted to determine this maximum value of resistance.

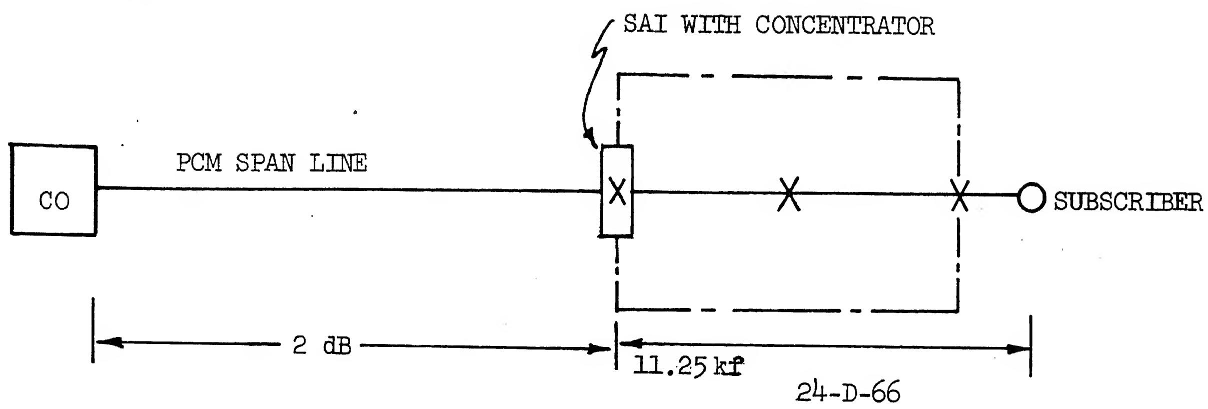
EXAMPLE 10



1. DC LOOP RESISTANCE		REFERENCE
31.5 kf, 24-D-66 x 51.89 ohms/kf =	1635 ohms	TABLE II
7 LP's x 6.0 ohms/LP =	42 ohms	
Total DC Loop Resistance	1677 ohms	
2. 1000 HZ LOSS		
31.5 kf, 24-D-66 x 0.233 dB/kf =	7.34 dB	TABLE I

Example 10 illustrate the use of a concentrator. Note that the concentrator trunk is a physical circuit.

EXAMPLE 11



1. DC LOOP RESISTANCE

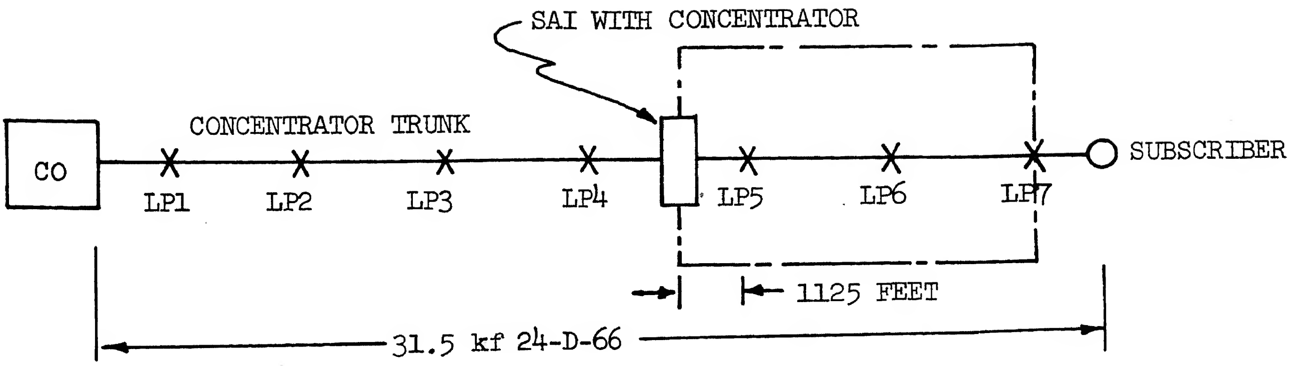
			REFERENCE
11.25 kf 24-D-66 x 51.89 ohms/kf	=	584 ohms	TABLE II
3 LP's x 6.0 ohms/LP	=	18 ohms	TABLE II
Total DC Loop Resistance		602 ohms	

2. 1000 HZ LOSS

			REFERENCE
11.25 kf 24-D-66 x 0.233 dB/kf	=	2.62 dB	TABLE II
PCM Carrier Loss	=	2.00 dB	TABLE III
Total 1000 Hz Loss		4.62 dB	

This example is the same as Example 10 except that the concentrator trunk is replaced by a PCM carrier system. Loading of the line beyond the SAI isn't necessary but the load coils may be left in if it is economically desirable to do so.

EXAMPLE 12



1. DC LOOP RESISTANCE

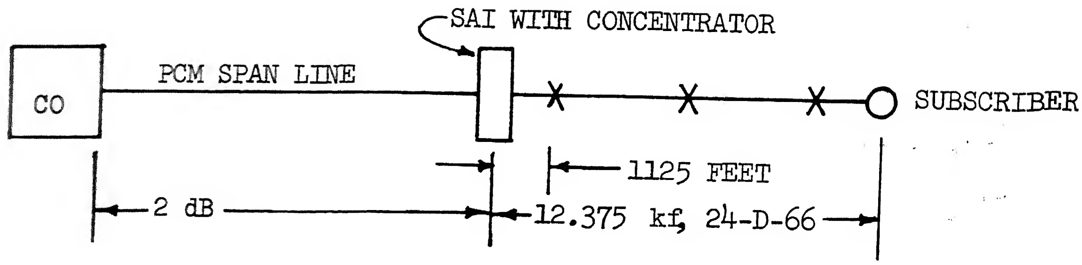
			REFERENCE
31.5 kf, 24-D-66 x 51.89 ohms/kf	=	1635 ohms	TABLE II
7 LP's x 6 ohms/LP	=	42 ohms	TABLE II
Total DC Loop Resistance		1677 ohms	

2. 1000 HZ LOSS

31.5 kf, 24-D-66 x 0.233 dB/kf = 7.34 dB

In this example the SAI is a shorter distance than the optimum
one-half section from the first load
not create any problem.

EXAMPLE 13



1. DC LOOP RESISTANCE

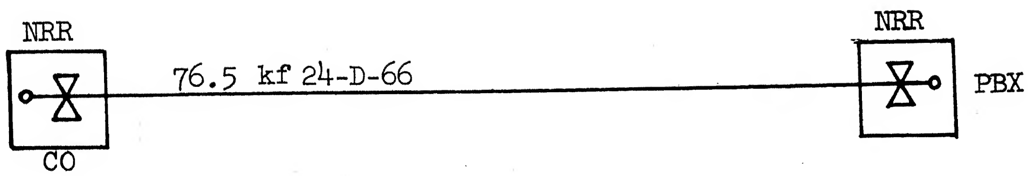
			REFERENCE
12.375 kf, 24-D-66 x 51.89 ohms/kf	=	642 ohms	TABLE II
3 LP's x 6 ohms/LP	=	18 ohms	TABLE II
		660 ohms	

2. 1000 HZ LOSS

			REFERENCE
12.375 kf, 24-D-66 x 0.233 dB/kf	=	2.88 dB	TABLE I
PCM Carrier Loss	=	2.00 dB	TABLE II
Total 1000 Hz Loss		4.88 dB	

As in Example 11, the load coils are not needed but they may be left in.

EXAMPLE 14



1.	**DC LOOP RESISTANCE**			REFERENCE
	76.5 kf, 24-D-66 x 51.89 ohms/kf	=	3970 ohms	TABLE II
	17 LP's x 6 ohms/LP	=	102 ohms	TABLE II
	2 NRR	=	120 ohms	TABLE II
	Total Loop Resistance		4192 ohms	

2.	**1000 HZ LOSS**			REFERENCE
	76.5 kf, 24-D-66 x 0.233 dB/kf	=	17.82 dB	TABLE I
	NRG 2x(- 7 dB)	=	-14.00 dB	TABLE III
	Total 1000 Hz Loss	=	3.82 dB	

This illustrates an exceptional case in which the PBX is located so great a distance from the central office that gain is required at both ends of the trunk.